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Flue Gas Desulfurization Sludge Establishment of Vegetation on Ponded and Soil-Applied Waste

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FLUE GAS DESULFURIZATION SLUDGE: ESTABLISHMENT OF VEGETATION ON PONDED AND SOIL-APPLIED WASTE

by

P. M. Giordano (TVA-Muscle Shoals)
D. A. Mays (TVA-Muscle Shoals)
and J. M. Soileau (TVA-Muscle Shoals)

Tennessee Valley Authority
Division of Agricultural Development
Muscle Shoals, Alabama 35660

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EPA Project Officer: Julian W. Jones

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

TVA Project Directors: J. C. Duggan (TVA-Chattanooga)
and J. L. Crowe (TVA-Chattanooga)
Tennessee Valley Authority
Division of Energy Demonstrations and Technology
Chattanooga, TN 47401

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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16. ABSTRACT

The report gives results of research to identify and evaluate forms of vegetation and methods of their establishment for reclaiming retired flue gas desulfurization sludge ponds. Also studied were the soil liming value of limestone scrubber sludge (LSS) and plant uptake and percolation losses of some chemical nutrients in the sludge. Several vegetation schemes were evaluated between 1977 and 1982 for covering and stabilizing LSS at Colbert Steam Plant, Cherokee, AL, and Shawnee Steam Plant, Paducah, KY. Eleven tree and 10 grass or legume species were tested for adaptability and survival when planted directly in LSS or in LSS amended with soil, municipal sewage sludge, or standard potting mix. Black locust, the most tolerant tree species, required one of the above amendments at planting for completely satisfactory growth and development. Performances of sycamore and cottonwood were fair in some tests, but both were markedly inferior to black locust. Bermudagrass, switchgrass, and sweet clover, thrive when planted directly in LSS or with soil cover, if adequate fertilizer was supplied. Based on lush stands of volunteer Phragmites communis (common reed) on adjacent scrubber ponds, this species may also have promise. Other studies indicated that LSS apparently has sufficient unreacted limestone to be a satisfactory soil liming agent.

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ABSTRACT

The main emphasis of this research was to identify and evaluate forms of vegetation and methods of their establishment for reclaiming retired flue gas desulfurization sludge ponds. Studies also were conducted to determine the soil liming value of limestone scrubber sludge (LSS) and plant uptake and percolation losses of some chemical nutrients in the sludge.

Several vegetation schemes were evaluated over a 5-year period (1977-1982) for covering and stabilizing LSS at Colbert Steam Plant, Cherokee, Alabama, and Shawnee Steam Plant, Paducah, Kentucky. Eleven tree and ten grass or legume species have been tested for adaptability and survival when planted directly in LSS or in LSS amended with soil, municipal sewage sludge, or standard potting mix. Black locust was the most tolerant tree species but required one of the above amendments at planting for completely satisfactory growth and development.

Performance of sycamore and cottonwood was fair in some tests, but both species were markedly inferior to black locust. Bermudagrass, switchgrass, and sweet clover thrived when planted directly in LSS or with soil cover, if adequate fertilizer was supplied. Based upon lush stands of volunteer Phragmites communis (common reed) on adjacent scrubber ponds, this species also may have promise.

Other studies indicated that LSS apparently has sufficient unreacted limestone to be a satisfactory soil liming agent, comparing favorably with agricultural limestone. Nutrient uptake by alfalfa growing on LSS-treated soil was not adversely affected. However, content of boron (derived from fly ash) was significantly higher in forage tissue and in percolate from LSS plots, particularly during the first year after application. Commercial use of LSS as a liming agent would be restricted to local use because of the unfavorable economics of handling and transportation.

This report summarizes research conducted from January 1, 1977 to September 30, 1981. It was submitted by the Tennessee Valley Authority in partial fulfillment of the project entitled "Study for Revegetation of SO_2 Waste-Disposal Ponds" under terms of Interagency Energy Agreement No. EPA-IAG-D8-E721 with the Environmental Protection Agency.

CONTENTS

		Page
Disclaimer		ii
Abstract		iii
Figures		v
Tables		vi
Section		
1	Introduction	1
2	Conclusions and Recommendations	2
3	Experimentation	3
	Colbert Sludge Pond	3
	Shawnee Sludge Ponds	4
	Muscle Shoals Rhizotron-Lysimeter Study	12
	Muscle Shoals Field Study	17
4	References	23
5	Appendix	24

FIGURES

Number		Page
1	Tree seedling establishment on a retired limestone scrubber pond at Shawnee Steam Plant, Paducah, Kentucky	5
2	Autumn olive (above) and black locust (below) three months after planting bare rooted seedlings	7
3	Volunteer stand of Phragmites communis (common reed) on a retired limestone scrubber pond at Shawnee Steam Plant, Paducah, Kentucky	10
4	Alfalfa growth on simulated ponded limestone scrubber sludge in the rhizotron-lysimeter facility at Muscle Shoals, Alabama	14
5	Alfalfa root development in rhizotron-lysimeter bins containing simulated ponded limestone scrubber sludge . . .	15

TABLES

Number		Page
1	Survival and growth of trees on the Colbert sludge pond two years after planting in 1977	4
2	Survival of trees on a Shawnee sludge pond two months after planting in 1978	6
3	Survival of trees on a Shawnee sludge pond 18 and 30 months after planting in 1979	8
4	Effect of soil cover on yield of several forage grasses	11
5	Some chemical characteristics of solid and liquid components in slurry from the Venturi (forced oxidation) and TCA (partly oxidized) limestone scrubber systems of SO_2 removal	13
6	Heavy metal concentrations in solids from the Venturi and TCA limestone scrubber systems	13
7	Total dry matter yield and mean concentration of chemical elements in alfalfa forage as related to application of limestone scrubber sludge in Decatur soil (1978-1980)	16
8	Total losses and concentrations of chemical elements in percolate as related to application of limestone scrubber sludges in Decatur soil (1978-1980)	18
9	Effect of agricultural limestone and limestone scrubber sludge on alfalfa yield (1979-1981)	20
10	Soil pH and nutrient content at varying soil depths in 1979, as affected by application of limestone scrubber sludge and agricultural limestone	21
11	Nutrient concentrations in alfalfa forage as affected by application of limestone scrubber sludge and agricultural limestone (1979-1980)	22

Section 1

INTRODUCTION

Flue gas desulfurization (FGD) is being accomplished most widely by wet scrubbing processes which result in huge quantities of a thixotropic sludge usually collected and retained in ponds (1, 9). Most sludges consist of varying mixtures of calcium sulfate, calcium sulfite, calcium carbonate, and calcium hydroxide plus fly ash (5). The following is a list of several management (2) or utilization (4) alternatives that have been proposed and evaluated to deal with this growing problem:

(a) Dewatering and landfilling
(b) Chemical treatment and landfilling
(c) Untreated waste ponding
(d) Chemical treatment and ponding
(e) Utilization as a soil amendment (liming agent) or in the building industry (wallboard).

Because of the large volume of sludge generated, the energy requirement for dewatering, transportation considerations, and a limited market for the resulting product (mainly gypsum), some form of stabilization of ponded waste appears to be a major feasible solution. Some degree of success has been attained through chemical treatment and landfilling techniques which have proven to be environmentally sound with respect to water quality as well as being relatively cost effective (2).

To improve aesthetics of the disposal areas, provide food and shelter for wildlife, and enhance future productivity of these retention sites, studies were begun in 1977 to identify and evaluate sources of vegetation and appropriate management practices for providing suitable land cover. The use of several tree and grass species for revegetation of mine spoils, ash ponds, and other disturbed areas has been successful (3, 6, 7). However, partially dewatered scrubber ponds present special problems with respect to plant establishment, fertilization, and species persistence. Studies are described which have addressed these issues through experiments conducted on a small pond at Colbert Steam Plant, Cherokee, Alabama, and on several sludge retention ponds at Shawnee Steam Plant, Paducah, Kentucky. Ancillary experiments were also conducted at Muscle Shoals, Alabama, to measure leachate quality from simulated ponded sludge in a rhizotron-lysimeter facility (8) and to determine the value of slurried limestone scrubber sludge (LSS) as a soil liming agent.

Section 2

CONCLUSIONS AND RECOMMENDATIONS

Subsequent to sufficient stabilization after retirement via natural dewatering processes (evaporation and percolation), certain forms of vegetation can be established successfully by direct planting in ponded LSS. However, better survival and more consistent stands can be attained using soil or organic amendments in the immediate rooting zone or for seedbed preparation. Black locust was far superior to other tree species tested, while common bermudagrass was the most aggressive and highest yielding forage plant tested. Several grasses and legumes would likely give adequate cover if a minimal soil cover (3-6 cm) was provided. Furthermore, experience at Shawnee Steam Plant suggests that ponded sludge will safely support such lightweight mechanized equipment as rototillers and small farm tractors. This would be necessary for revegetation and management operations on larger ponds like the 50 ha storage site at Widows Creek Steam Plant, Stevenson, Alabama.

Although LSS is a satisfactory soil liming agent (about 50 percent as effective as agricultural limestone), the economics for processing and transportation are not favorable. Also, the vast quantities generated would quickly saturate the market demand because of the need to use the product at locations close to the source. There appear to be no serious environmental constraints associated with the use of LSS as a soil amendment if inordinate amounts of fly ash are not incorporated.

It is recommended that existing plantings at Shawnee Steam Plant be periodically monitored to confirm persistence and rate of development. More effort should be directed toward determining the most practical and effective techniques for planting containerized tree stock. Areas needing investigation include identification of optimal potting mixes and container sizes, fertility requirements for optimum production of grasses and trees, and planting mechanization. Also, estimates of potential for economic return from revegetated ponds are needed. Possible benefits from the production of hay or pasture, forest products, biomass for fuel, and wildlife cover should be evaluated.

Section 3

EXPERIMENTATION

Colbert Sludge Pond

Several species of bare rooted tree seedlings (autumn olive, bald cypress, cottonwood, European alder, river birch, sycamore)* were planted in a small (185 m^2) limestone sludge retention pond on April 8, 1977. The pond had been retired for about 2 years before the planting. The partially dewatered sludge was of mixed composition representating accumulation of several experimental wastes from the 1-MW flue gas desulfurization pilot plant at Colbert Steam Plant.

A 15-20 cm surface layer of the sludge was removed from half of the ponded area and replaced with soil from an adjacent area. Four trees each of the above 6 species were planted in a random pattern directly into the LSS and the soil-LSS portions of the pond. No fertilizer or other amendments were supplied at planting.

Survival rate of most species was good during the first year. Of the total 48 trees planted, 35 appeared to be well established after 1 year. No river birch plantings survived. Very little distinction could be made at that time between growth of trees planted with or without soil cover. The entire area was fertilized in April 1978 with a 13-13-13 formulation at a rate of about 450 kg/ha.

Trees were observed again in July 1978 and were showing a significantly greater rate of growth where soil was layered over LSS. However, survival remained similar under both planting conditions. Cottonwood and sycamore appeared to be superior to the other species, growing to a height of over 3 m during the first 15 months and showing excellent foliage color. European alder and autumn olive showed signs of stress but seemed to be well established. Although several bald cypress died, those surviving appeared healthy. Also, several volunteer black locust seedlings from the area surrounding the pond were growing vigorously and showing no signs of stress.

By April 1979 only the cottonwood and sycamore trees were growing satisfactorily (Table 1). Overall tree height was comparable on both halves of the pond, but trees appeared healthier on the soil-covered half. Growth of the surviving autumn olive, European alder, and bald cypress trees was so retarded that these species could not be considered as suitable cover. After another year (1980), several cottonwood and sycamore trees had grown to a height of about 7 m and appeared to be thriving on the LSS pond; other species continued to decline. By 1981 the area had become overgrown with volunteer vegetation and locust seedlings, and no further observations can be made.

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*See appendix for scientific names of plants.

TABLE 1. SURVIVAL AND GROWTH OF TREES ON THE COLBERT SLUDGE POND TWO YEARS AFTER PLANTING IN 1977

Species planted†	In sludge only		In soil-covered sludge	
	Survival (no.)	Height (m)	Survival (no.)	Height (m)
Cottonwood	3	2.5-3.0	4	2.5-3.0
Sycamore	2	1.5-2.5	4	2.0-2.5
European alder	3	0.3-1.0	2	1.5-2.0
Bald cypress	2	1.0-1.5	0	0
Autumn olive	0	0	1	1.5
River birch	0	0	0	0

†Four trees of each species were planted in sludge only and in soil-covered sludge in 1977.

Shawnee Sludge Ponds

Vegetative plantings were made over the period 1978-1981 on a 0.5-ha retired LSS pond at Shawnee Steam Plant in Paducah, Kentucky (Figure 1). As was the case for the Colbert pond, composition of the sludge was varied and stratified from previous collection of wastes derived from several scrubbing processes. Sufficient natural dewatering had occurred so that the area was stable enough to work with small equipment. The adaptability of a wide range of plant species such as trees, grasses, and legumes was evaluated using amendments such as soil, municipal sewage sludge, and commercial potting mixes to improve seedbed preparation and initial plant establishment.

Tree studies--

The first planting at Shawnee in April 1978 consisted of 9 species of bare-rooted tree seedlings arranged in a randomized block design with 4 replicated plots. Each plot was composed of 6 rows of 9 trees, with 3 rows planted directly in the LSS and 3 rows in holes filled with aerobically digested and dewatered municipal sewage sludge from a wastewater treatment plant in Florence, Alabama. A survival count was made in late June (Table 2). Although rainfall was adequate shortly after planting, conditions became extremely dry in May and June resulting in appreciable leaf drop and some mortality.

Except for European alder and cottonwood, early establishment of the other species was equal or better with sewage sludge in the planting hole compared with direct planting in the LSS. Black locust was far superior to other species (Figure 2), and river birch was intolerant to the conditions of the LSS pond, thus confirming early results from the Colbert pond. By late fall 1978 only black locust had persisted in sufficient number to continue evaluation. By September 1980 these trees exhibited an 80 percent survival where sewage sludge had been placed in the planting holes, but there was less than 10 percent survival of those planted in unamended LSS. The plantings in sewage sludge were about 2.5 m in height and had stem diameters ranging from 4-8 cm.

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Figure 1. Tree seedling establishment on a retired limestone scrubber pond at Shawnee Steam Plant, Paducah, Kentucky.

TABLE 2. SURVIVAL OF TREES ON SHAWNEE SLUDGE POND TWO MONTHS AFTER PLANTING IN 1978

Species planted	Tree survival, %	
	With sewage sludge	Without sewage sludge
Black locust	96	85
Autumn olive	85	70
Weeping willow	78	78
Green ash	78	70
European alder	70	85
Sycamore	67	59
Cottonwood	37	56
River birch	37	37
Sweet gum	26	26

A second planting made in April 1979 included autumn olive, sycamore, cottonwood, and black locust. All trees from the 1978 planting (except the surviving black locust) were replaced with the above species by planting in the same holes. At the time of planting the site was relatively dry and firm despite 23 cm of rainfall during the previous 2-week period. This leads to speculation as to the actual need for chemical stabilization of LSS ponds before reclamation.

Excellent stands of black locust and sycamore persisted through the summer and fall of 1979 where planted in sewage sludge-filled holes; survival was reduced markedly where seedlings were planted directly in LSS. Cottonwood and autumn olive had about 60 percent survival with sewage sludge and less than 25 percent without. By September 1980 the pattern remained about the same (Table 3). Black locust had reached 2.5-3.0 m in height with stem diameters exceeding 2.5 cm. Final observations were made in October 1981 (Table 3). Stands of black locust continued to persist, but sycamore, cottonwood, and autumn olive stands were reduced markedly. Tree height of the black locust averaged over 5 m and 4 m on stands established in 1978 and 1979, respectively.

In April 1980 black locust, cottonwood, autumn olive, and bicolor lespedeza were planted directly in LSS or in holes filled with soil; 40 plants of each species were planted in each manner. No trees of any species survived from direct planting in the sludge. Soil amendment resulted in survival of 70 and 25 percent of the black locust and cottonwood, respectively, after 18 months; all autumn olive and bicolor lespedeza died. Extreme heat and drought conditions which prevailed during much of the summer in 1980 lowered the survival rates.

Figure 2. Autumn olive (above) and black locust (below) three months after planting bare rooted seedlings.

TABLE 3. SURVIVAL OF TREES ON A SHAWNEE SLUDGE POND 18 AND 30 MONTHS AFTER PLANTING IN 1979

Species planted	Tree survival, %			
	With sewage sludge		Without sewage sludge	
	18 months	30 months	18 months	30 months
Black locust	82	74	48	37
Sycamore	60	26	56	30
Cottonwood	17	7	8	7
Autumn olive	16	4	6	4

Black locust and honey locust trees were started from seeds in the Muscle Shoals TVA greenhouse and transplanted to pots containing Pro-Mix, a standard potting mixture used for ornamentals. In mid-April 1981, 100 seedlings of each species were planted directly in the LSS but without removing the Pro-Mix from the roots. By October 1981 black locust survival was 90 percent and plant height ranged from 1-2 m. About 75 percent of the honey locust trees were living but were badly damaged from rabbit foraging. It did not appear likely that the stand of honey locust would persist.

Black locust and cottonwood were planted in April 1979 on two small retired LSS ponds a short distance from the larger pond discussed above. This test was to determine the suitability of these ponds to sustain trees after being closed from disposal activity and covered with a soil layer varying in depth. Sites selected for tree establishment were a pond containing sludge which had been chemically treated (pond A), a pond containing untreated sludge which had been conditioned by underdraining (pond B), and a control area adjacent to the two ponds. Soil cover depth on pond A was about 90 cm. On pond B it increased from about 40 cm at the shallow end to 66 cm at the deep end. Tree plantings consisted of 90 bare-rooted seedlings of each species (black locust and cottonwood) on pond A, 45 seedlings of each on pond B, and 50 of each on the control area.

There were excellent stands of black locust observed in October 1981 especially on the ponded sites; some reduction of stand occurred on the control site, probably due to the poor physical condition of the soil which was severely scalped. Tree height ranged from 3-5 m and was unaffected by the depth of soil cover. Cottonwood mortality was high on all sites with the best survival (23 percent) occurring on pond A. It is likely that the soil cover was so deep as to preclude any sludge effect on the trees.

Grass and legume study--

An area along the west bank of the large LSS was retained for establishment of several grass and legume species. In June 1978 bermudagrass, serecia, and switchgrass were sown on plots (8 m^2) consisting of LSS (unaltered), 5 cm of soil tilled into the top 5 cm of sludge, 5 cm of soil as a layer over the sludge, and 10 cm of soil as a layer over the sludge. All treatments were in triplicate. The entire plot area was fertilized with a 13-13-13 formulation at a rate equivalent to 550 kg/ha. Several cool season grasses and legumes (alsike clover, ladino clover, crown vetch, birdsfoot trefoil, reed canarygrass, and tall fescue) were planted in September 1978. Because of a severe weed infestation (bermudagrass and nutsedge), the area was fumigated with methyl bromide in May 1979 and replanted in June (bermudagrass, serecia, switchgrass) and in September (cool season grasses and legumes).

Bermudagrass provided the most vigorous cover of all the herbaceous species evaluated. Growth was similar on all soil amended plots but was somewhat less vigorous on unamended LSS.

Switchgrass grew most vigorously on plots with 10 cm of soil but stands were adequate on other plots. This species naturally produces less dense cover and is lower yielding than bermudagrass.

Tall fescue and reed canarygrass developed somewhat sparse stands which were marginally adequate to provide protection against wind and water erosion, but yields were too low for efficient forage production. It appeared that the vigor of tall fescue was reduced by heavy and continuous rabbit grazing during much of the year.

None of the seeded legumes were successfully established except that crown vetch developed a good stand on plots with the deepest soil cover. Several volunteer species developed moderate amounts of cover on soil amended plots as well as on various other areas of the LSS pond.

Sweet clover grew on several soil covered plots where competition from seeded species was lacking and became established around many tree planting sites where soil, sewage sludge, or fertilizers had been added. It appeared to grow well on unamended sludge once plants become established.

Crabgrass and fall panicum invaded many areas where exposed soil or organic matter was not covered with other vegetation.

After fertilization in 1982, hop clover (an annual) developed a good stand on most soil covered plots which did not have perennial grasses on them. A number of annual weeds also grew well after fertilization.

Common reed (Phragmites communis), which grows vigorously around the edges of a nearby ash pond, invaded the LSS pond and grew well but does not appear to have any economic usefulness (Figure 3).

Figure 3. Volunteer stand of Phragmites communis on a retired limestone scrubber pond at Shawnee Steam Plant, Paducah, Kentucky.

While the general mix of volunteer species appeared to produce an adequate amount of cover for control of wind and water erosion and for wildlife habitat, the yields appeared to be too low for them to provide an economic return from a revegetated LSS pond.

During 1982 an experiment was conducted to measure the productivity of well fertilized bermudagrass, switchgrass, and reed canarygrass. Replicated plots with good stands of these species were uniformly fertilized at the rate of 56 kg of phosphorus and 112 kg of potassium/ha in April. Nitrogen in the form of ammonium nitrate was applied at an annual rate of 168 kg/ha on switchgrass and reed canarygrass and 336 kg/ha on bermudagrass. The nitrogen was split into three uniform amounts and applied in April, June, and August. Forage yields were measured three times during the year using standard small plot harvesting techniques.

The data in Table 4 show that excellent yields of forage can be grown on property managed LSS ponds. Bermudagrass yields were as good on soil amended sludge as they would ordinarily be on well fertilized agricultural soils in that part of Kentucky. The yield was lower without soil amendment but still adequate for use as a pasture.

Switchgrass yields were normal on all treatments while reed canarygrass yields were not really adequate even with 10 cm of soil cover.

The data from this experiment indicate that common bermudagrass is probably the most satisfactory species to use in revegetation of LSS ponds in areas where it is winterhardy. In addition to having highly desirable yield levels, the plants produce both underground rhizomes and aboveground stolons. This means that if only a sparse stand results from seeding, the creeping habit of growth will soon result in a solid cover of grass.

The primary disadvantage of bermudagrass is that it requires routine fertilization with nitrogen to remain vigorous and productive.

TABLE 4. EFFECT OF SOIL COVER ON YIELD OF SEVERAL FORAGE GRASSES

Soil added	Dry forage, metric tons/ha		
	Switchgrass	Bermudagrass	Reed canarygrass
10 cm cover	10.1	17.2	4.1
5 cm cover	9.4	17.9	3.7
5 cm mixed	8.4	18.2	1.7
None	8.8	12.9	1.6

Muscle Shoals Rhizotron-Lysimeter Study

An experiment was conducted from April 1978 to June 1980 to study effects of two LSS on alfalfa growth and on percolation losses of several chemical elements from amended Decatur clay loam (Rhodic Paleudult). Rhizotron bins were filled to a depth of about 160 cm with Decatur subsoil (pH 5.0) in December 1977. Limestone scrubber sludge solids from two scrubber designs at Shawnee Steam Plant (the Venturi and TCA systems) were then applied in duplicate to bins in late December. A 15-cm thick layer of the "forced oxidation" Venturi or "partly oxidized" TCA scrubber sludge solids were covered with about 7 cm of topsoil. Chemical characteristics of solid and liquid components of the two batches of scrubber sludges obtained for this study reflected the effects of oxidation on relative amounts of sulfate and sulfite in the sludge materials (Table 5). Most of the liquids were decanted from the settled solids and the resultant thixotropic sludge was placed in the rhizotron bins. As further characterization of the limestone scrubber sludges the solids were also analyzed for total zinc (Zn), cadmium (Cd), copper (Cu), nickel (Ni), and manganese (Mn) (Table 6).

Just before seeding with alfalfa on April 10, 1978, fertilizer (40 g concentrated superphosphate, 80 g KCl, 200 g $CaCO_3$, and 75 g $MgCO_3$) was applied and lightly raked into the surface soil of these bins and also to a bin containing soil only. More fertilizer at the same rates was broadcast in each bin on March 12, 1979, and March 13, 1980. Supplemental irrigation was applied to all bins during prolonged periods of moisture stress each year. Alfalfa top and root growth was monitored, and forage clippings were made periodically from 1978 through 1980 for analysis of total nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and boron (B). Percolation water losses were recorded, and monthly composite percolate samples were analyzed for concentrations of Ca, Mg, Na, S (as SO_4), and B from April 1978 to June 1980. A suction pressure of about 25 cm Hg (1/3 bar negative pressure) was maintained in the soil percolation and water collection system.

Observations of young plants in May 1978 indicated normal growth with both sources of limestone scrubber sludge (Figure 4). Counts of alfalfa roots along the plexiglass surface from May 17 to July 15, 1978, revealed very extensive root proliferation in the soil only and LSS treatments, including good root penetration through the layer of scrubber sludge material (Figure 5).

The total dry matter yield and mean concentration of N, P, K, Ca, Mg, S, Na, and B in forage clippings are given in Table 7 for 1978, 1979, and 1980. For all 3 years, alfalfa forage yields from the two LSS sources were from two- to fivefold higher than from the soil only treatment. There were no yield differences between the forced oxidation and partly oxidized LSS treatments.

TABLE 5. SOME CHEMICAL CHARACTERISTICS OF SOLID AND LIQUID COMPONENTS IN SLURRY FROM THE VENTURI (FORCED OXIDATION) AND TCA (PARTLY OXIDIZED) LIMESTONE SCRUBBER SYSTEMS OF SO_2 REMOVAL

Limestone scrubber system	Solids				Liquid				
	Ca	Total S	Sulfate	Sulfite	Ca	Mg	Total S	Sulfate	Sulfite
	(%)				(ppm)				
Venturi (forced oxidation)	19.71	11.41	11.28	0.13	3,910	2,234	847	841	6
TCA (partly oxidized)	19.10	10.83	1.97	8.86	1,455	456	816	750	67

TABLE 6. HEAVY METAL CONCENTRATIONS IN SOLIDS FROM THE VENTURI AND TCA LIMESTONE SCRUBBER SYSTEMS

Limestone scrubber system	Concentrations of heavy metals in limestone scrubber sludge solids				
	Zn	Cd	Cu	Ni	Mn
	(ppm)				
Venturi (forced oxidation)	275	3	26	24	150
TCA (partly oxidized)	181	2	19	24	111

Figure 4. Alfalfa grown on simulated ponded limestone scrubber sludge in the Rhizotron-lysimeter facility at Muscle Shoals, Alabama.

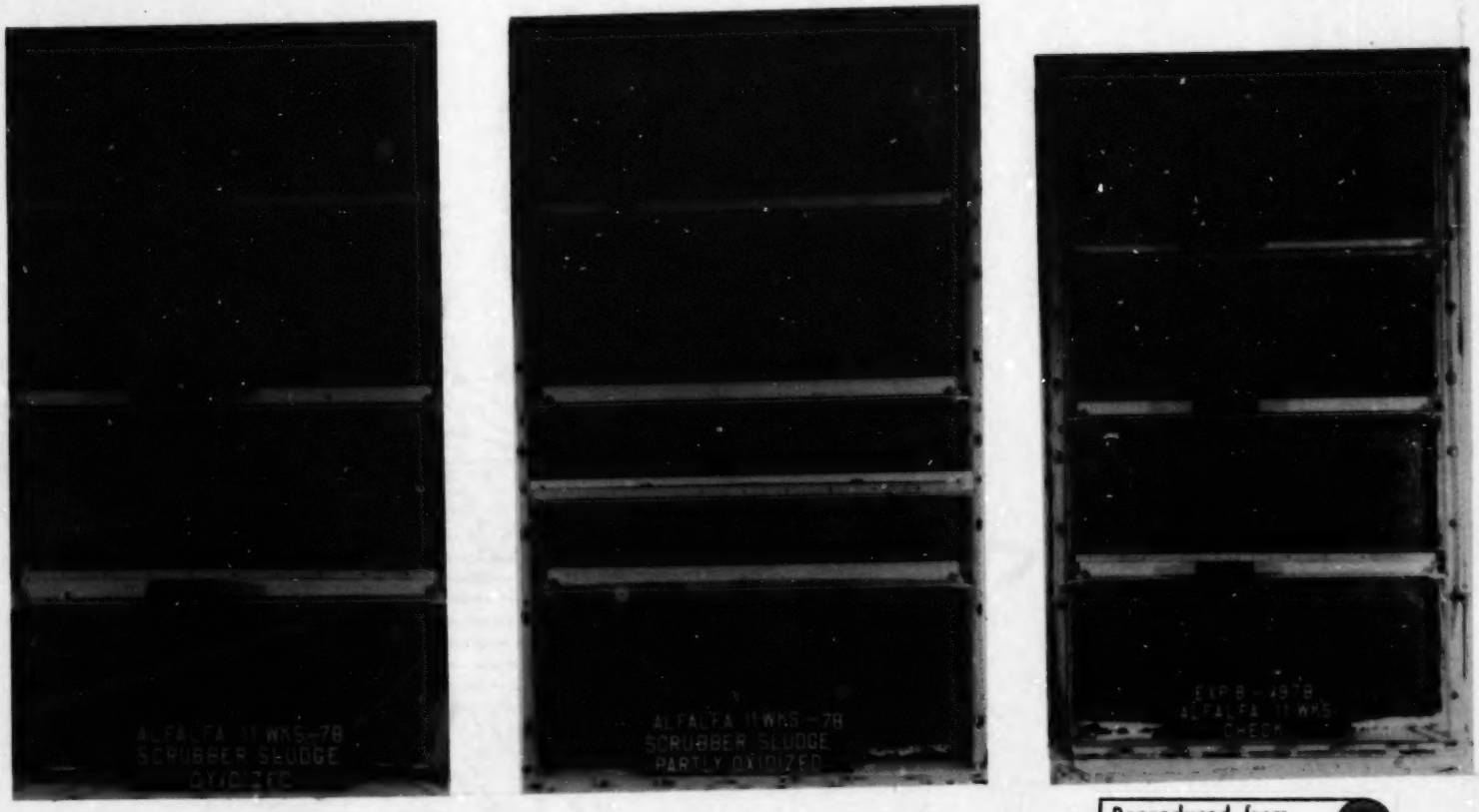

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Figure 5. Alfalfa root development in Rhizotron-lysimeter bias containing simulated ponded limestone scrubber sludge.

TABLE 7. TOTAL DRY MATTER YIELD AND MEAN CONCENTRATION OF CHEMICAL ELEMENTS IN ALFALFA FORAGE AS RELATED TO APPLICATION OF LIMESTONE SCRUBBER SLUDGES IN DECATUR SOIL, 1978-1980

Treatment	Year	Total dry matter	Mean concentration of elements in alfalfa forage							
			N	P	K	Ca	Mg	S	Na	B
		(kg/bin)	(%)							(ppm)
Venturi (forced oxidation)	1978	0.57	2.5	0.21	1.7	1.4	0.30	0.26	0.07	163
	1979	2.00	3.1	.26	2.0	1.4	.19	.24	.05	35
	1980	1.34	2.7	.16	2.5	.8	.27	.29	.07	34
TCA (partly oxidized)	1978	0.59	2.5	0.20	1.7	1.5	0.34	0.27	0.07	134
	1979	1.90	3.1	.27	2.0	1.4	.22	.23	.07	37
	1980	1.28	2.6	.16	2.4	.8	.27	.30	.05	28
Soil only	1978	0.28	2.5	0.20	1.6	1.6	0.32	0.24	0.04	21
	1979	0.56	2.8	.29	2.1	1.2	.24	.17	.04	15
	1980	0.31	2.4	.15	2.5	.5	.29	.15	.05	9

Concentrations of B were significantly higher in alfalfa forage from the two LSS treatments than from the check. The concentration of B in 1978 alfalfa forage probably approached the plant toxicity range; the accumulation of B in subsequent years, however, was significantly reduced. Limestone scrubber sludge contained considerable fly ash material, which is usually high in B. Concentrations of Ca and S in alfalfa forage were similar among all treatments during 1978 and 1979; but, by 1980 they were higher in the LSS treatments than in the check. Concentrations of N, P,K, Mg, and Na in alfalfa clippings were similar among treatments for each of the 3 years studied.

As shown in Table 8, the total amount of percolation water lost from the bins within the April 10, 1978, to June 17, 1980, period (2.2 years) ranged from 2,052 to 2,679 liters. These volumes are equal to the amount of water contributed to the surface of one bin with 165 and 216 cm of rainfall, respectively. Within a 2.2-year percolation monitoring period, total amounts and mean concentrations of Ca, Mg, Na, S (as SO_4), and B in percolate were significantly higher from both LSS bins than from the check bin. The forced oxidation scrubber sludge had somewhat higher concentrations and total losses of these elements in percolation water than the partly oxidized sludge (Table 8). Monthly monitoring of percolation losses from LSS-treated soil bins indicated that Ca, Mg, S, and B were increasingly being mobilized through the profile with time (1978 through June 1980) whereas, Na leaching losses peaked during 1979. The slightly acid pH 5.4 of percolate from LSS treatments, compared with pH 6.0 from the soil only treatment (Table 8), was probably due to release of sulfates from the LSS. During 1980, the mean concentrations of S (as SO_4) in percolate from the forced oxidation and partly oxidized LSS had increased to 350 and 258 mg/liter, respectively.

Based upon results from this experiment, it is likely that growth and development of most plants will not be adversely affected by components of LSS either in terms of root development and proliferation or chemical uptake. In the event of excessive fly ash content in the LSS, certain B sensitive crops may be affected, such as beans as well as grasses and small grain which have a minimal requirement for B. The significance of the elevated chemical content of the percolate from the LSS-treated soil is not known; however, the concentration of B likely would preclude use for irrigation.

Muscle Shoals Field Study

An experiment was begun at the TVA Agricultural Research Farm in the fall of 1976 to compare the response of alfalfa to soil applications of LSS and agricultural limestone. Treatments applied in mid-September included several rates each of dry limestone or a slurry of LSS from Colbert Steam Plant. All treatments were incorporated into Decatur clay loam by disking into the soil surface. Seeding of alfalfa was unsuccessful in 1976 and again in the fall of 1977 because of adverse weather conditions. An excellent stand was achieved, however, in the spring of 1978, and yield data were collected from 1979 to 1981.

TABLE 8. TOTAL LOSSES AND CONCENTRATIONS OF CHEMICAL ELEMENTS IN PERCOLATE AS RELATED TO APPLICATION OF LIMESTONE SCRUBBER SLUDGES IN DECATUR SOIL, 1978-80

Treatment	Percolation volume†	Total percolation losses					Mean percolate concentrations					
		Ca†	Mg†	Na†	S†	B††	Ca†	Mg†	Na†	S†	B††	pH§
	(liters/bin)	(g/bin)					(mg/liter)					
Venturi (forced oxidation)	2,501	427	183	31	316	21.5	171	74	12	125	17.3	5.4
TCA (partly oxidized)	2,209	199	83	20	206	5.0	90	38	9	93	4.3	5.4
Soil only	2,679	11	5	6	1	0.3	4	2	2	1	0.2	6.0

†April 10, 1978 to June 17, 1980, totals or weighted mean concentrations of monthly samples.

††June 10, 1979 to June 17, 1980, totals or weighted mean concentrations of monthly samples.

§Nonweighted means of monthly samples taken from April 10, 1978 to June 17, 1980.

The data in Table 9 show that LSS at the rates applied was at least as effective as agricultural limestone in promoting good alfalfa growth. The reason for the apparent superiority of the very high rates of LSS application is not clear. It is possible that the higher subsoil pH (Table 10) and greater supply of Ca in the subsoil were beneficial. Furthermore, higher S and B contents of the alfalfa forage with the higher sludge rates may have contributed to the yield increases (Table 11).

While both agricultural limestone and LSS raised the soil pH in the 0 to 15-cm zone, only the LSS had a marked effect from 15 to 30 cm; soil at depths below 30 cm was unaffected (Table 10). Concentrations of P, K, and Mg were not influenced by soil amendment. However, content of Ca, S, and B was higher throughout the 60-cm profile following application of the LSS.

It is apparent from these results that LSS is satisfactory for use as a liming material. Adding excessive fly ash to sludge for stabilization could result in B toxicity to sensitive crops under some soil conditions. The actual extent of use for agricultural purposes will depend on the economics of transportation and application relative to commercial agricultural limestone.

TABLE 9. EFFECT OF AGRICULTURAL LIMESTONE AND LIMESTONE SCRUBBER SLUDGE ON ALFALFA YIELD, 1979-1981

Liming material	Rate	Yield		
		1979	1980	1981
		metric tons/ha		
Limestone scrubber sludge	10	13.9 c†	8.0 b	14.4 bc
	20	14.4 bc	8.5 ab	14.5 bc
	40	16.0 ab	8.9 ab	15.7 abc
	160	16.3 ab	9.1 ab	16.3 ab
	320	16.7 a	9.9 a	17.2 a
Agricultural limestone	5	15.7 abc	8.7 ab	15.1 bc
	10	15.2 abc	8.3 ab	14.6 bc
	20	15.2 abc	8.0 b	14.1 c

†Yields followed by the same letter are not significantly different at the 5% confidence level according to the Duncan Multiple Range Test.

TABLE 10. SOIL pH AND NUTRIENT CONTENT AT VARYING SOIL DEPTHS IN 1979 AS AFFECTED BY APPLICATION OF LIMESTONE SCRUBBER SLUDGE AND AGRICULTURAL LIMESTONE

Liming material	Rate	pH	P	K	Ca	Mg	S	B
	metric tons/ha		kg/ha					
		0- to 15-cm depth						
Limestone scrubber sludge	10	6.0	629	152	5,412	115	115	1.0
	40	6.3	526	173	6,381	116	163	1.3
	320	6.3	510	104	11,155	128	11,354	3.2
Agricultural lime	10	6.2	556	140	5,522	123	72	0.9
	20	6.4	401	103	7,282	178	67	0.8
		15- to 30-cm depth						
Limestone scrubber sludge	10	4.9	168	125	2,492	148	215	1.2
	40	4.8	212	138	2,872	77	278	1.5
	320	5.3	189	132	5,697	69	3,796	3.2
Agricultural lime	10	4.8	204	115	2,445	157	213	1.1
	20	4.9	163	109	2,405	166	213	1.1
		30- to 45-cm depth						
Limestone scrubber sludge	10	4.8	34	105	1,828	227	383	1.0
	40	4.7	36	127	1,788	131	515	1.0
	320	4.9	20	118	3,908	84	1,057	3.5
Agricultural lime	10	4.8	22	87	1,523	195	398	0.9
	20	4.7	25	90	1,609	187	416	1.0
		45- to 60-cm depth						
Limestone scrubber sludge	10	4.7	18	82	1,476	245	488	0.8
	40	4.6	23	93	1,809	199	593	1.0
	320	4.9	11	91	2,408	196	1,039	2.7
Agricultural lime	10	4.8	22	75	1,458	219	194	0.7
	20	4.7	40	67	1,540	236	203	0.8

TABLE 11. NUTRIENT CONCENTRATIONS IN ALFALFA FORAGE AS AFFECTED BY APPLICATION OF LIMESTONE SCRUBBER SLUDGE AND AGRICULTURAL LIMESTONE

Liming material	Rate	Year	Nutrient concentration, %†				
			Ca	Mg	K	S	B
Limestone scrubber sludge	10	1979	1.16	.18	2.83	.17	.0015
		1980	1.57	.24	2.17	.25	.0024
	20	1979	1.33	.19	2.56	.19	.0020
		1980	1.56	.24	2.00	.24	.0026
	40	1979	1.26	.16	2.82	.20	.0021
		1980	1.60	.20	2.30	.25	.0027
	160	1979	1.26	.14	2.88	.23	.0025
		1980	1.60	.18	2.31	.30	.0039
	320	1979	1.29	.14	2.83	.22	.0025
		1980	1.69	.17	2.37	.32	.0040
Agricultural lime	5	1979	1.21	.17	2.75	.20	.0021
		1980	1.55	.23	2.28	.26	.0023
	10	1979	1.25	.18	2.59	.18	.0016
		1980	1.60	.25	2.08	.24	.0023
	20	1979	1.32	.20	2.48	.19	.0016
		1980	1.55	.25	1.89	.25	.0020

†Values represent mean concentrations of 5 and 3 cuttings in 1979 and 1980, respectively.

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APPENDIX

List of Plant Names

Common name	Scientific name
Trees and Shrubs:	
Autumn olive	Elaegnus umbellata
Bald cypress	Taxodium distichum
Bicolor lespedeza	Bicolor lespedeza
Black locust	Robinia pseudoacacia
Cottonwood	Populus trichocarpa
European alder	Alnus glutinosa
Green ash	Frzxinus pennsylvanica
Honey locust	Gleditsia triacanthos
River birch	Betula nigra
Sweet gum	Liquidamber styraciflua
Sycamore	Platanus accidentalis
Weeping willow	Salix babylonica
Grasses and Legumes:	
Alfalfa	Medicago sativa
Alsike clover	Trifolium hybridum
Bermudagrass	Cynodon dactylon
Birdsfoot trefoil	Lotus corniculatus
Common reed	Phragmites communis
Crown vetch	Coronilla varia
Fall panicum	Panicum dichotomiflorum
Hop clover	Trifolium agrarium
Ladino clover	Trifolium aepens
Reed canarygrass	Phalaris arundinacea
Sericea lespedeza	Lespedeza cuneata
Smooth crabgrass	Digitaria ischaemum
Sweet clover	Melilotus alba
Switchgrass	Panicum virgatum
Tall fescue	Festuca elatior